HIGH ACTION THYRISTORS FOR PULSED APPLICATIONS*

H. Singh and C. R. Hummer
U. S. Army Research Laboratory AMSRL-WM-TE Bldg. 120
Aberdeen Proving Grounds, MD 21005-5066

Abstract

High Energy Pulsers for various applications have been constructed by utilizing several different classes of high action switches. Most commonly used switches are high-pressure spark gaps, vacuum switches of varying architectures and solid state thyristors with different gate structures. All these categories of switches are capable of switching large number of coulombs. Spark gaps and vacuum switches have life time dependent on accumulated total coulomb transfer as a dominant rating factor. For the solid state thyristors, the action (current squared times pulse width) is the most significant parameter. Thyristors hold potential for applications in rugged duty, long life high-energy pulsers. Thyristors with different gate structures have been investigated. These thyristors have been designed for commercial low frequency applications. To use them for intended pulsed applications, the gate structure must be optimized, so that the rate of plasma spreading across the wafer is increased to switch maximum peak current at desired di/dt. 125 mm thyristors with different gate structures were tested on a 3.7 mF capacitor bank that had a resistance of 9 mΩ and an inductance of 800 nH. Measurements of the current through the thyristor and the voltage drop across it show that power dissipated by the device could be reduced if the plasma-spreading rate could be increased.

I. INTRODUCTION

The U. S. Army Research Laboratory ARL is investigating the many possible applications of pulse power in a future combat vehicle. One application is to power a rail-gun to launch a projectile to high velocity for piercing armor [1]. A complementary application is to power a coil-gun that will launch a counter-munition against incoming missiles [2]. Another application is to deliver a large current to a shaped charge jet that is penetrating the vehicle's armor. The large current can drive the inherent hydrodynamic instabilities, and greatly reduce its penetration into the armor [3]. Research in these areas and others has advanced to the point that it is possible to state separately the pulse power requirements for each use. It is not known how to integrate these various components into a singe pulse power system as would be found in a combat vehicle. A significant advancement towards the integration of all these applications would result if high action thyristors could be used. Unfortunately, the available thyristors cannot satisfy all the requirements for a full scale rail-gun or a full scale coil-gun. They may, however, be used in the following examples of a sub-scale rail gun and sub-scale coil gun that are used for research.

II. PULSE POWER EXAMPLES

The first example is a pulsed alternator powering a rail gun. One type of a pulsed alternator stores energy in the form of a rotating cylinder. A field winding located on the outside surface of the cylindrical shell will produce a magnetic field with six poles when a current is passed through it. Once the magnetic field is produced, voltages are induced by the rotating magnetic field in armature windings that are mounted on a stationary cylindrical shell surrounding the rotor. The armature windings are electrically connected in three groups ϕ_1, ϕ_2 and ϕ_3 forming a 6-pole/3-phase generator.

The three phase coils and the field coil are connected to a circuit Figure 1 that will eventually be made of thyristors which control and direct the currents. In the present experiments, the circuit contains diodes for rectification of the current for the field and the load. The sequence for the operation of the pulsed alternator is controlled by explosively closing switches and explosively opening switches. The ends of the phase coils connect to a full-wave rectifier bridge whose output is connected to the field coil L_f and to a half-wave rectifier bridge whose output is connected to the load. The other ends of the phase coils are connected to a common ground in a "Y" configuration. After the rotor has been spun up, a small "seed" current is started in the field coil by an auxiliary capacitor bank, not shown in Figure 1, to produce a small magnetic field. This magnetic field induces alternating currents in the phase coils which are full-wave rectified and directed to the field coil by the "Pos. Bus Bar" and the "Neg. Bus Bar". This additional current through the field coil will continue to increase, if

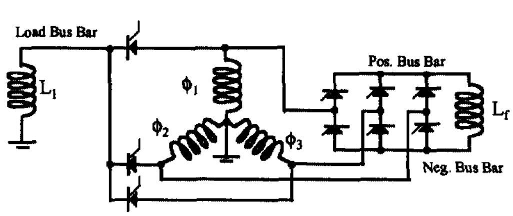

Figure 1. Pulsed Alternator Circuit

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14. ABSTRACT
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the current gain is greater than the energy losses. Thus the field coil current is "self-excited" from a small seed current up to a larger current by using some of the rotational energy. After the field coil current reaches the desired level, the thyristors to the "Load Bus Bar" are closed to deliver current to the load.

The current for a thyristor in the full-wave bridge Figure 2 and a thyristor to the load Figure 3 were calculated by using a lumped circuit model [4]. The currents were found by numerically solving the coupled differential equations for the circuits, the equation of motion of the rotor and the equation of motion of the projectile. In this case, the load was a 3.0 m rail gun with an inductance gradient of 360 nH/m launching a 0.32 kg projectile. The action for these currents are 1.4×10^7 a^2s for the full-wave bridge thyristor, Figure 2, and 6.3×10^8 a^2s for a thyristor to the load Figure 3.

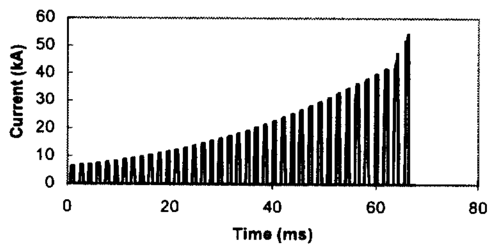

Figure 2. Thyristor Current In The Full-Wave Bridge.

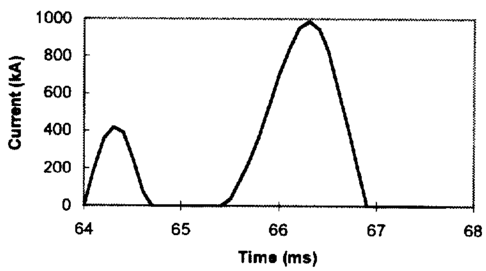

Figure 3. Thyristor Current To The Rail Gun.

The other example is a coil gun that launches a plate edge-on towards the target. In this launcher, a time varying magnetic induction produced by an external launch coil induces a current in the plate to be launched. This action is similar to that of a transformer where the primary winding, the external launch coil, induces a current in the secondary winding, the plate. The force between the induced current and the external magnetic induction accelerates the plate out of the coil. The electrical schematic of a coil gun is very similar to a series LRC circuit. Unlike the classic LRC circuit, the inductance associated with the launcher depends on the position of the plate within the coil. The resistor represents the energy losses within the system that may also vary with time, but it is usually assumed to be constant. If a coil gun were to launch a 500 g plate to a velocity of 400 m/s, the switch must pass a current pulse that is approximately a half sine wave with a maximum current of 250 kA and a half period of 660 μs, and the switch must withstand an action of approximately 1.9×10^7 a^2s. The initial charge on the 8.3 mF capacitor bank is 8 kV. Spark gap switches were the only switches that could satisfy these conditions.

III. SPCOs 125mm THYRISTORS

The 125mm thyristors made by SPCO could be used in these examples if they were operated in series or in parallel, and if their pulse carrying capabilities were better known. Thus thyristors with an involute gate structure Figure 4 and a highly interdigitated gate structure Figure 5 were tested on a 3.7 mF capacitor bank with a series inductance of 800 nH and a series resistance of 9 mΩ.

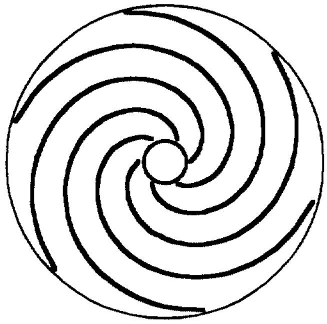

Figure 4. Involute Gate Structure

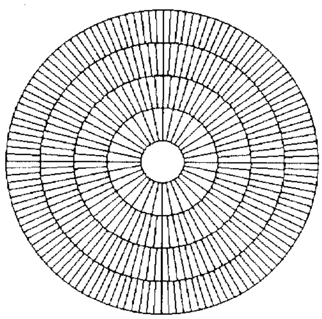

Figure 5. Highly Interdigitated Gate

The involute gate structure has been tested to peak currents of 175 kA and to initial di/dt that is greater than 3.3 kA/μs. The projected maximum peak current and maximum di/dt ratings of the interdigitated gate structure are > 200 kA and >15 kA/μs respectively. All these ratings are greater than an earlier design where the gate structure was a star pattern radiating from the center. The improved ratings of the interdigitated gate structure come from the higher velocity of the plasma across the wafer when the thyristor is turned on. To get an indication of the different plasma velocities of the two thyristors, the voltage drop across them were recorded when the capacitor bank was charged to 2.0 kV and the thyristors were turned on Figure 6. These results show that the voltage across the thyristor with the interdigitated gate drops quickly within 15 μs when the thyristor with the involuted gate still has a substantial voltage drop.

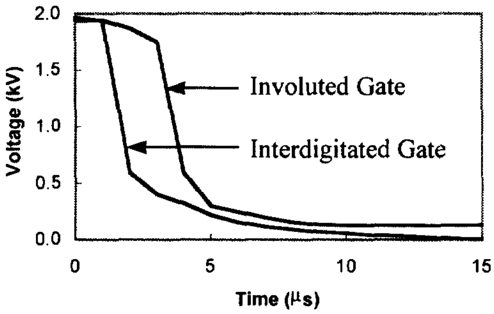

Figure 6. Thyristor Voltage Drop

Thus the power dissipation by thyristor with the interdigitated gate was much less, as shown in Figure 7.

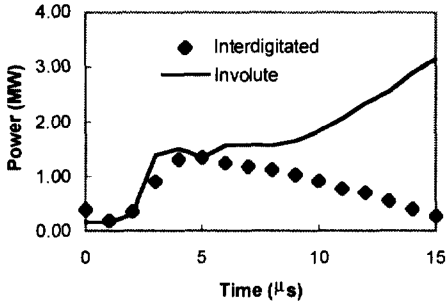

Figure 7. Power Dissipation

Resistive elements of the capacitor bank were removed to test for the peak current capabilities of the thyristor with the interdigitated gate structure. This reduced the capacitor bank resistance to about 3 mΩ and the bank inductance was reduced to 450 nH. In a series of tests, the initial voltage of the capacitor bank was increased in steps of 500 V up to 2 kV. When the capacitor bank was charged to 2.0 kV, the pulse had a peak current of 150 kA and a half period of 145 µs. The action for this current pulse was appproximatly 1.6×10^6 a^2s and it had a maximum di/dt of 3.4 kA/µs. The thyristor broke down while it was conducting current with the initial voltage of 2.5 kV on the capacitor bank. The data suggest that the thyristor may have broken down after its recovery time. The peak current was 190 kA and had a maximum di/dt of 4.3 kA/µs. Eventhough the reverse voltage spike on the thyristor was limited by a snubber circuit, a 0.15 Ω resistor in series with a 100 µF capacitor, examination showed pitting around the edge of the wafer. This pitting may be due to over voltage or improper clamping of the electrodes. These tests will be repeated with a more robust clamping arrangement.

IV. CONCLUSIONS

The interdigitated gate structure has been demonstrated to have increased the rate of the plasma spreading across the wafer. This results in the voltage across the thyristor to decrease faster than the other gate designs. Thus, the total energy that the thyristor must dissipate during the time that the voltage drop across it is decreasing and the current through it is increasing has been reduced. This should allow the thyristors to handle higher current pulses, withstand higher action and be useful in the above applications.

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